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Light Emitting Diode (LED) Red Buoy Light

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NOTICE

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16. Abstract

At the present time, the U.S. Coast Guard (USCG) employs the 155MM lantern as the standard equipment used on lighted buoys and many small fixed structures. This lantern uses a tungsten lamp as a light source and a colored lens to filter out the unwanted color when green or red lights are desired. This method of obtaining colored light is inefficient. A prior Research and Development Center effort developed a green direct emitting fluorescent light but failed to deliver a useful red light. This Research Associate Project was undertaken to investigate the use of Light Emitting Diodes (LEDs) as a possible red minor aids-to-navigation light.

It was found that a small LED package mounted in a circle with a plastic thin film Fresnel lens was the preferred design. A prototype of 120 LEDs mounted in the above configuration was able to provide a 4-mile nominal range light. This is the most common range light presently in use on buoys. The low cost, high reliability and long life of LEDs are convincing reasons to pursue further efforts in this area. Other possible advantages of LED usage are the ability to design the LEDs to a package that allows the passage of wires and/or supports to the top of the buoy. This can be critical when several apparatuses need to be at the top of the buoy. Finally, the ability to flash LEDs at a very fast rate could allow the Coast Guard to monitor the status of buoys with an optical receiver, while the mariner would perceive the light as being continuous.

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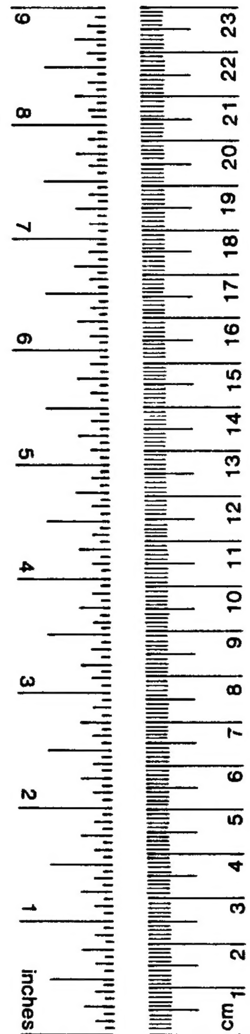
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

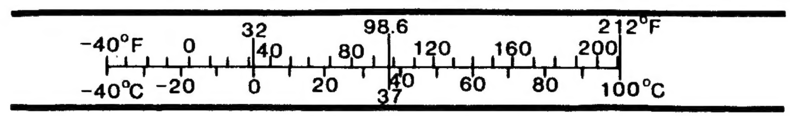
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

A low cost Research Associate Project was initiated in 1993 to investigate the possible use of red Light Emitting Diodes (LED) as minor (buoys and small structures) aids-to-navigation lights. A Research Associate Project is a low cost, short term, investigation into a quick pay off project by an individual in the Coast Guard[1]. This work was authorized by the Research and Development Center and Commandant (G-ER)[2] and was to be conducted on a part time and not to interfere with normal duties basis. The majority of work conducted on this project was conducted during off duty hours and thus contributed to the length of this effort. Funds in the amount of $3000.00 were appropriated for this work from the Select Projects funding of the CG Research and Development Center (R&D Center).

The development of a small fluorescent light at the R&D Center for Aids To Navigation (ATON) use sparked interest in direct emitting sources of light. The green fluorescent prototype developed was efficient and had the correct color output. However, the red fluorescent was not as efficient and did not have an acceptable color output. This lack of an appropriate red source was the primary reason an investigation into LEDs was initiated.

LED PROPERTIES AND CHARACTERISTICS

In order to make any decisions concerning the use of Light Emitting Diodes (LEDs) in minor aids to navigation lighting, it is necessary to understand their basic properties and characteristics. A LED is an electroluminescent diode which produces light due to radiative recombination. When a current is induced in this type of diode, electrons are displaced from their normal orbits to a higher energy state. When the electrons revert to their normal (lower) energy state, energy is given off in the form of photons of light. This difference in energy level between the excited state and the normal state is called the band gap energy and has discrete values for a given material. The color of light given off is thus dependent on the material used in the diode. The formula to determine the predominate wavelength of a LED is given below in Equation 1:

$$\lambda = h * c / Eg \tag{1}$$

$$(\lambda = c / f, \quad Eg = h * f)$$

Where, h: Plank's constant $\rightarrow 6.626 \times 10^{-34}$ (J*s)

c: Velocity of light $\rightarrow 3 \times 10^{8}$ (m / s)

Eg: Band gap energy (J)

f: Frequency (s^{-1})

[1] HQINST 5401.6

[2] Commandant (G-ER) approval letter dated 11 Dec. 1992

As an example, a red LED constructed of gallium (Ga), aluminum (Al), and arsenic (As), has a band gap energy of 3.044×10^{-19} Joules. Using Equation 1, the emitted light is therefore in the red spectrum at 653 nanometers.

LEDs are nearly monochromatic sources and therefore their efficiency is increased due to being a direct emitting light when compared to the Coast Guard standard incandescent light and filter system. The figure below demonstrates the relative spectral energy of a Hewlett Packard (HP) green LED and a (HP) red LED as compared to the spectrum of a CG standard incandescent lamp. Information for this and subsequent graphs was obtained directly from HP literature. Specification sheets for individual HP products are available directly from the manufacturer upon request.

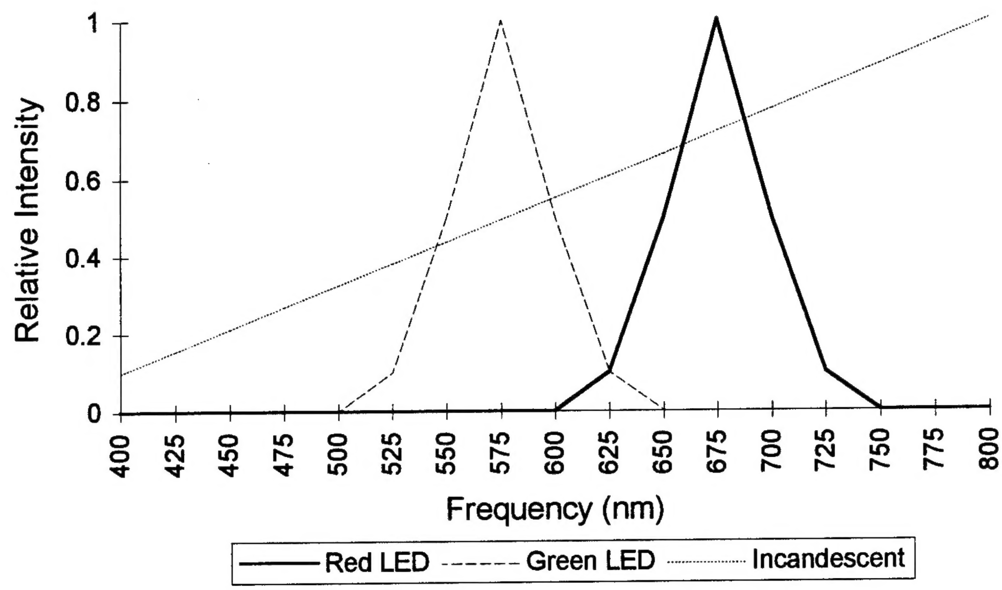

Figure 1. Output Intensity vs Wavelength

The maximum relative intensity of a particular LED is determined by the material used in the positive and negative portions of the diode. Where these two dissimilar portions of the diode meet is called the P-N junction. The relative intensity is determined by the materials used in the P-N junction and the current allowed to flow through that junction. The ambient temperature influences the junction temperature, which in turn also affects the relative intensity.

Normal test conditions are at a DC current of 20 milliamps (ma), maximum junction temperature of 110 degrees Celsius, and ambient temperature of 25 degrees Celsius. A plot of intensity versus ambient temperature is shown in Figure 2. The -2 % gradient of the red LED points out the importance of operating at reasonable ambient temperatures. This can be ensured by allowing for adequate ventilation in the system design and/or using a pulse driven circuit to decrease the energy generated at the junction of the LED.

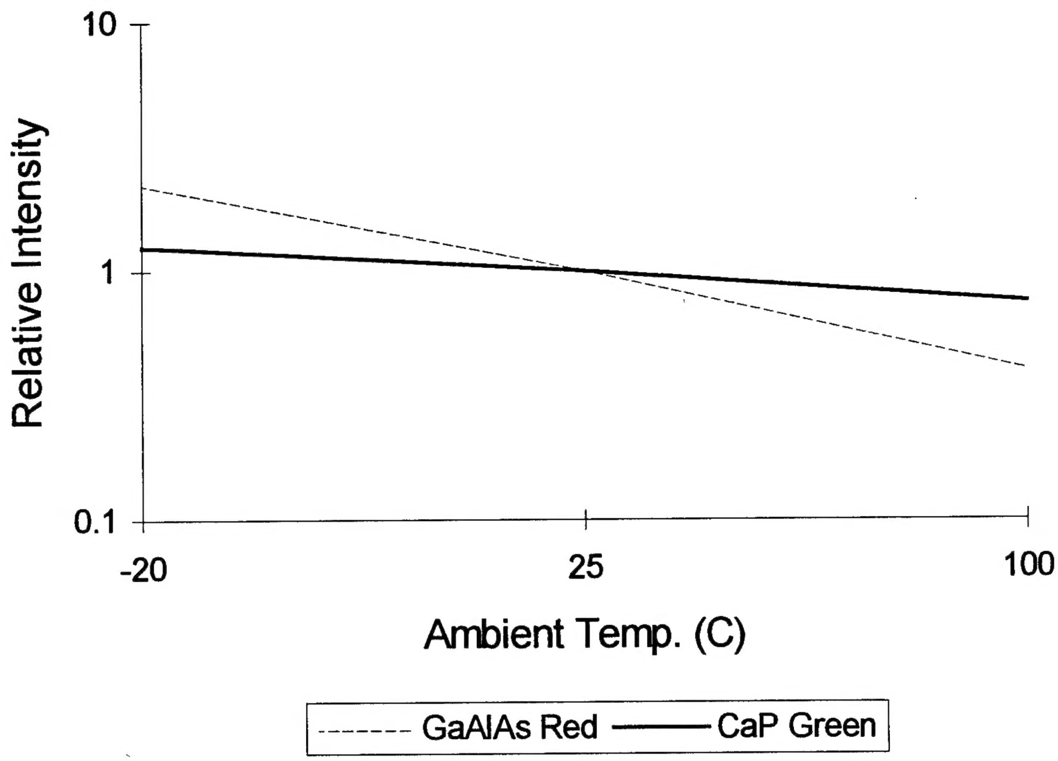

Figure 2. LED Output Intensity vs Ambient Temperature

The relative luminous intensity versus forward current is shown in Figure 3. This graph demonstrates the almost linear relationship between current and output intensity in LEDs. Note that this is only true over their normal operating range and the output intensity is not linear at currents of greater than 50 ma. While LEDs can handle larger currents for short periods of time, they are normally operated between 20 and 50 ma to obtain a reasonable lifetime.

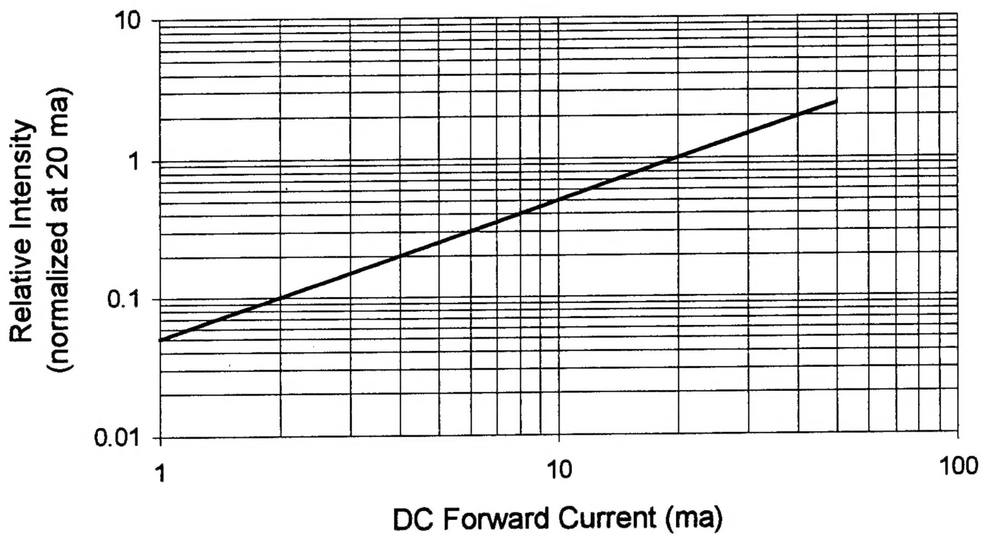

Figure 3. LED Output Intensity vs Forward Current

The voltage drop across a LED is a function of the P-N junction material used. In the case of a GaAs red LED, a range of 1.5 to 2.0 volts DC is observed depending on the current through the device. A plot of voltage drop versus current is shown in Figure 4.

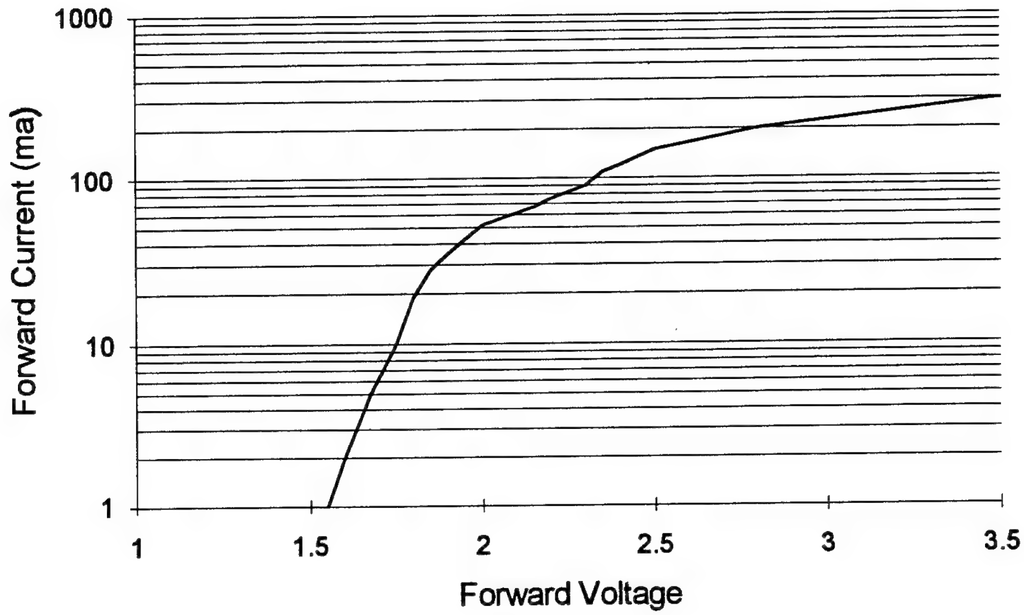

Figure 4. LED Voltage vs Current

RESEARCH EFFORT

An extensive product search was conducted to identify candidate LEDs for further testing. While many companies are now conducting research and development into higher output LEDs, Hewlett Packard (HP) has been the leader in this technology for many years. Two packages from HP were identified as having the highest output and highest efficiency of those presently available. A red T-4 package (model HLMP-8150) and a red T-1 3/4 package (model HLMP-8103) were purchased and tested. The T-1 3/4 package is 5 mm wide, which is approximately the size of a pencil eraser and has a relatively wide beam spread. The T-4 package is 13.3 mm wide, which is approximately the size of the end of your thumb and has a much smaller and more concentrated beam width. The manufacturer's stated beam widths for these lamps are shown in Table 1.

Table 1. Beam Widths of HP LEDs

LED		Vertical Beam Width			Horizontal Beam Width	
Package		@ 50 %	@ 10%		@50%	@10%
T-1 3/4		+/- 5 deg	+/- 20 deg		+/- 5 deg	+/- 20 deg
T-4		+/- 1.5 deg	+/- 3.5 deg		+/- 1.5 deg	+/- 3.5 deg

The specifications for these HP LEDs are indicative of most LEDs on the market and can be used for generalizations concerning the use of LEDs in aids to navigation. A LED can be switched on and of at frequencies over 100 Megahertz, with a response speed of 45 nanoseconds. The maximum reverse voltage is typically 8 volts DC but can be as high as 20 VDC. Peak wavelength is at 654 nanometers (nm) and the dominant wavelength derived from the CIE[3] chromaticity diagram and representing the color of the device is at 644 nm. This color is in the allowable region as defined by the International Association Of Lighthouse Authorities[4]. Last, but certainly not least, is the expected life and mean time between failure (MTBF) ratings. LEDs are extremely reliable devices having MTBFs on the order of 5 to 10 million hours. This does not in any way mean they will last that long; it simply means that in a sample batch of 1000 lamps that HP tested for over 5000 hours, they had only one infant failure. (Infant failure is when an electronic device fails very early in its expected life.)

The life of a LED is defined as the point where 50% of the lamps will fail and is typically greater than 100,000 hours when operated at 20 milliamps (data provided from LED suppliers and confirmed by Hewlett Packard engineers). If LEDs are operated at higher currents, the expected life is decreased. No data is currently available for these new LEDs for higher currents, but an engineering rule of thumb used by HP personnel is to de-rate the life by twice the current increase over the reference standard of 20 ma. A LED operated at 40 ma can be expected to only last 25,000 hours. To put these hours in perspective, a lamp burning at 20 ma continuously for twelve hours a day and 365 days a year would not need replacing for 22.8 years! A lamp operated at a higher current (40 ma in our example), that "only" lasts 25,000 hours, would need to be replaced every 5.7 years!

DESIGN CRITERIA

The design of a LED red minor aid-to-navigation light starts with an analysis of the existing incandescent Coast Guard standard lanterns. The 155MM lantern is the standard equipment used on lighted buoys in the Coast Guard and is also used in lower intensity shore installations. It can be equipped with a .25, .55, .77, 1.15, or a 2.03 ampere lamp. A survey of the First and Eighth Coast Guard Districts usage of lamps is shown in Table 2 and indicates that the majority of 155MM lanterns use either the .55 or the .77 ampere lamp. The Luminous Intensities of Aids to Navigation Lights (COMDINST M16510.2) lists the output of a red lensed 155MM lantern with a .55 and .77 lamp as 35 and 52 candela respectively. This equates to the low and high end of 6.7 kilometer (4 mile) nominal range respectively.

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[3] Commission Internationale de I'Eclairage (CIE), *COLOURS OF LIGHT SIGNALS*, Publication Number 2, 1959

[4] I.A.L.A. , *RECOMMENDATIONS FOR THE COLOURS OF LIGHT SIGNALS ON AIDS TO NAVIGATION*, DEC 1977

Table 2. 1st and 8th CG District Lamp Distribution in 155MM Lantern

Lamp Amperage	.25	.55	.77	1.15	2.03
Number in use by 1st Dist.	13	249	812	215	40
Number in Use by 8th Dist.	32	1,242	890	# Not Available	

A 155MM lantern has approximately a 5 degree vertical divergence at the 50% power points. The T-4 LED has a 3 degree divergence as shown in Table 1 and an output of 30 candela at 20 ma. Output rises to 50 candela at 40 ma. Therefore, it does not require a lens to achieve the desired output. Since the horizontal beam width is also 3 degrees, 120 LEDs are necessary to overlap at the 50% power points to ensure a relatively even horizontal distribution. The 360 degree horizontal beam is then provided by 120 LEDs mounted 3 degrees apart.

The T-1 3/4 LED has a vertical and horizontal beam width of approximately 10 degrees as shown in Table 1. This necessitates the use of a lens to narrow the vertical divergence and increase the peak output. Several lens and mirror combinations were investigated and pertinent literature reviewed. A plastic thin film Fresnel lens was chosen for use due to the material flexibility, corrosion resistance, ease of installation, and extremely low price. The 3M corporation provided six each of 304mm long by 25.4 mm high by 1mm thick thin film Fresnel lens as engineering samples.

PROTOTYPES

Two prototypes were constructed to investigate the benefits and problems of the T-4 and T-1 3/4 LEDs in a practical application. A Coast Guard Aids to Navigation unit in the Ninth District attempted to utilize a few LEDs mounted on a pre-focus collar. While this prior non-R&D effort did not yield a useful lamp, it did put the R&D Center in contact with a small display company willing to do experimental work. Data Display Products built both prototype circuits based on information provided by the R&D Center.

The T-4 LED package is 13.3mm (1/2 inch) in diameter. In order to provide 360 degrees of horizontal coverage, 120 LEDs would be necessary. If they were mounted in a single large diameter disk, it would be extremely large and unwieldy (greater than 508mm diameter circle). It was therefore decided to mount 20 LEDs on six (127mm diameter) disks stacked vertically. Each LED was mounted 18 degrees apart and each disk was shifted 3 degrees from the one above and/or below it. Schematic and construction diagrams are enclosed as Appendix A. A photograph of the engineering prototype is shown in Figure 5.

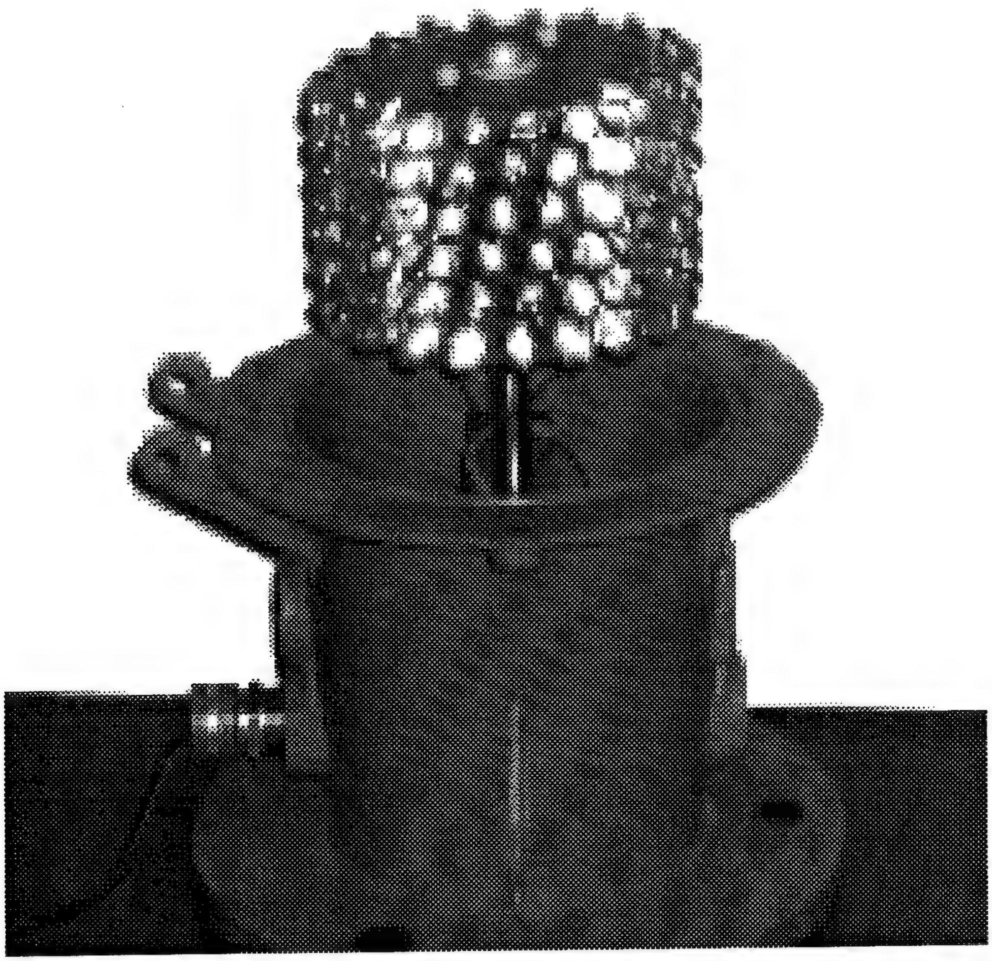

Figure 5   T-4 Prototype System

The T-1 3/4 LED package is 5mm (1/4 inch) in diameter and therefore the 120 LEDs necessary to provide 360 degree horizontal coverage can be mounted in a reasonably sized disk (an 11 inch diameter disk). This configuration also enables the use of a lens to increase the peak output and decrease the vertical divergence. Two 1/4 inch thick acrylic plates were cut to hold the thin film Fresnel lens in a machined groove. These grooves were cut at a radius of 25.4mm (one inch) larger than the circle of LEDs to position the LEDs at the focal point of the lens. Schematic and construction diagrams are enclosed as Appendix B. A photograph of the engineering prototype is shown in Figure 6.

Both prototypes were wired in the same manner. A series parallel circuit was wired such that groups of six LEDs are in series with each other and can be directly connected to a 12 VDC supply. This results in a 40 to 45 ma current through each LED and is an acceptable current level. A lower input voltage would result in a lower current and consequently a lower intensity output. This also has the advantage of providing reverse voltage protection to greater than 48 VDC. If the power is connected backwards, the diodes are in reverse polarity and no current will flow. Each of the six series LEDs is also in parallel with 20 other series LEDs. This matrix of 20 by 6 LEDs results in very high reliability due to redundancy. If one LED fails, all other LEDs remain operational and simply increase in current by less than 5%.

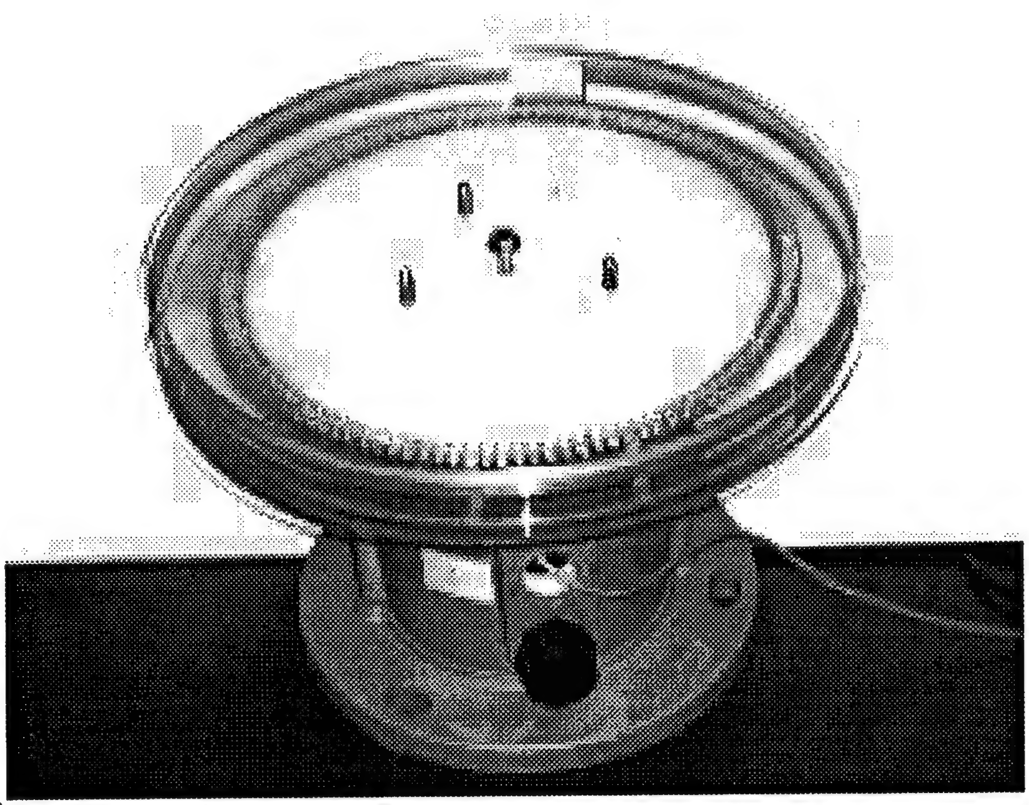

Figure 6. T-1 3/4 Prototype System

PROTOTYPE RESULTS AND CONCLUSIONS

The T-4 prototype system was found to have a very high peak output. The output was very high in some areas but not consistent across the entire horizontal beam. A complete intensity scan is included as Appendix C. The alignment of each individual T-4 package becomes critical when no external lens is utilized. At the current cost of $10 per LED, it is also a very costly package. The prototype from Data Display Products cost $2100 to construct. While the cost of high output LEDs is decreasing, it may be some time before this package becomes economically feasible. The poor consistency of the horizontal output and the high price, remove the T-4 prototype from further investigation at this time.

The T-1 3/4 prototype system was found to have a relatively consistent output, but not as high a peak as the T-4 prototype. A complete intensity scan is included as Appendix D. The measured peak intensity of 40 candela falls between the current .55 and .77 ampere lamps when used in a red 155MM lantern. The T-1 3/4 prototype system would provide a 4 mile nominal range. The use of a thin film Fresnel lens makes the alignment of individual LEDs less critical. While alignment is important, the lens effectively evens out the highs and lows to produce a more evenly distributed output. The T-1 3/4 LEDs are much less expensive. At approximately $1.00 per LED, the prototype circuit board was fabricated for $300 in the spring of 1994. Data Display Products offered some estimates of these circuit boards for larger quantities; $231 for 25, $161 for 50, $153 for 100, and $131 for 1,000.

POSSIBLE IMPROVEMENTS

The T-1 3/4 package has several additional possible benefits. The disk used for mounting the LED array is fabricated from a large printed circuit board and could conceivably hold all necessary regulation and flash circuitry along with the LEDs. This integrated unit could replace the existing lampchanger, flasher, and daylight control. Due to the large diameter disk and the LEDs mounted on the edge, it is possible to make the assembly a toroid shape. The large diameter hole in the center of the disk could be used to accommodate wire runs and solar panel supports.

Another possible benefit of LED lamps is their ability to be switched on and off at any desired rate. The LEDs could be multi-flicked to increase detectability. A multi-flick is a series of individual flicks comprising a single flash. Recent research in this area by Specialty Devices Incorporated[5], under a separate small business contract to the Coast Guard, has indicated the possibility of improved detectability by the use of the appropriate flick rate. If the flick rate is fast enough, the light appears to be continuous. However, if the flick rate is low enough the peripheral vision of the observer can possibly detect this

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[5] MTS Proceedings 1994 , *MULTI-FLICK STROBE MINOR AID TO NAVIGATION* by CWO2 Bruce Roberts and Paul Higley

signal better than a continuous light. More research is necessary in this area to determine the benefits and possible draw backs to this method.

The ability to switch on and off at a high rate could also be used for two other purposes. The junction temperature of the LED can be reduced and the life of the LED extended if the LED is switched on and off. This pulsed operation would be at a very high frequency and would be completely undetectable to the observer. Energy savings are also possible using this method if the pulse width is also varied. The duty cycle of the pulsed waveform could be varied to obtain different power consumption in lieu of adjusting the current through the LEDs. Either method of power consumption control would also affect the effective intensity.

The second possible use of pulsing the LED assembly is the ability to pass information. This could be utilized to obtain buoy status monitoring capability by Coast Guard units. A vessel would only need to proceed to within visible range of the buoy in order to receive its status update being transmitted. The mariner would perceive the light as continuous, but the Coast Guard could use an optical receiver to obtain buoy status information.

The T-1 3/4 package also lends itself to the ability of stacking multiple units to increase intensity and range. While a single unit could be utilized to replace the existing .25, .55, and .77 ampere Coast Guard lamps in a 155MM lantern, several units would be needed to replace the 1.15 or 2.03 ampere lamps. The T-1 3/4 package could be designed with a simple plug that mates with the unit below it so that the number of desired units would simply stack one on top the other. At only 38 mm (1 1/2 inches) high, the units could easily be bolted together to form larger arrays.

Since this unit is so short in height and large in diameter, it is conceivable that the solar panel could be incorporated into the top of the unit. Thin film deposit techniques make it possible to install a solar panel on almost any surface. A group of Ni-Cad or Lead-Acid batteries could be incorporated in a base unit to make a completely self-contained portable unit.

RELATED EFFORTS

The Japanese Maritime Safety Agency is conducting research on the use of LEDs in aids to navigation.[6] Their work involved the use of a highly polished reflector to obtain the desired beamwidth. The LEDs were mounted on a ring facing inward to the reflector, while the whole assembly was encased in a clear cover. The use of a special reflector makes this lantern more expensive than a lensed lantern. However, the long life of these products may make the added expense a minor point. A LED lantern similar to that described in the IALA paper is currently available from Zeni Lite International Co., Ltd. of Japan.

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[6] IALA Proceedings1990, *DEVELOPMENT OF LED LIGHT FOR SHORT RANGE LIGHTED AID* , by Senji Tanaka, Naomasa Kitamura, and Eifumi Miyamura

The French Service Maritime du Nord Agency is also conducting research on the use of LEDs in aids to navigation.[7] Their work paralleled the U.S .Coast Guard's efforts in the T-4 type package as described earlier. The use of individually focused LEDs has advantages due to the absence of reflectors or lens, but has the disadvantages of high cost per LED and the alignment of each LED becomes critical. The Gisman Corporation of France plans to market several LED minor aids-to-navigation products similar in design to that detailed in the IALA paper.

FUTURE WORK

While the red LED appears to adequately meet the output needs for minor aids to navigation, work remains to be done on green and white LEDs. Continuous research and development has been conducted on LEDs over the past few years to increase the red and green outputs and develop a reliable blue LED. The needs of the automotive industry (rear brake lights), billboards and large screens have been driving the industry to produce higher output devices and lower prices. While the current green LEDs are only 1/4 to 1/3 as intense in output as the red LEDs, several manufacturers are working on increasing the output of green LEDs to the level of present red LEDs.

Finally, while the green LED is currently not as high an output as the red, it does have some uses and a promising future. More investigation into several areas is highly recommended. The subject of multi-flick operation deserves more investigation. The mariner's feedback on these intensely red lanterns deserves looking into. The power regulation and built-in flash controller circuitry could be investigated further to realize more cost and stock system savings. Life testing in the marine environment of different manufacturer's products could give the Coast Guard a baseline of information for LED products. In conclusion, the LED lamp appears to have a bright future (pun intended) as a minor aid to navigation light.

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[7] IALA Proceedings 1994, *ON THE USE OF ELECTROLUMINESCENT DIODES(LED) IN AIDS TO NAVIGATION*, by H. Dernier

REV.	DATE	BY	DESCRIPTION
-	940124	NN	PRELIMINARY ONLY

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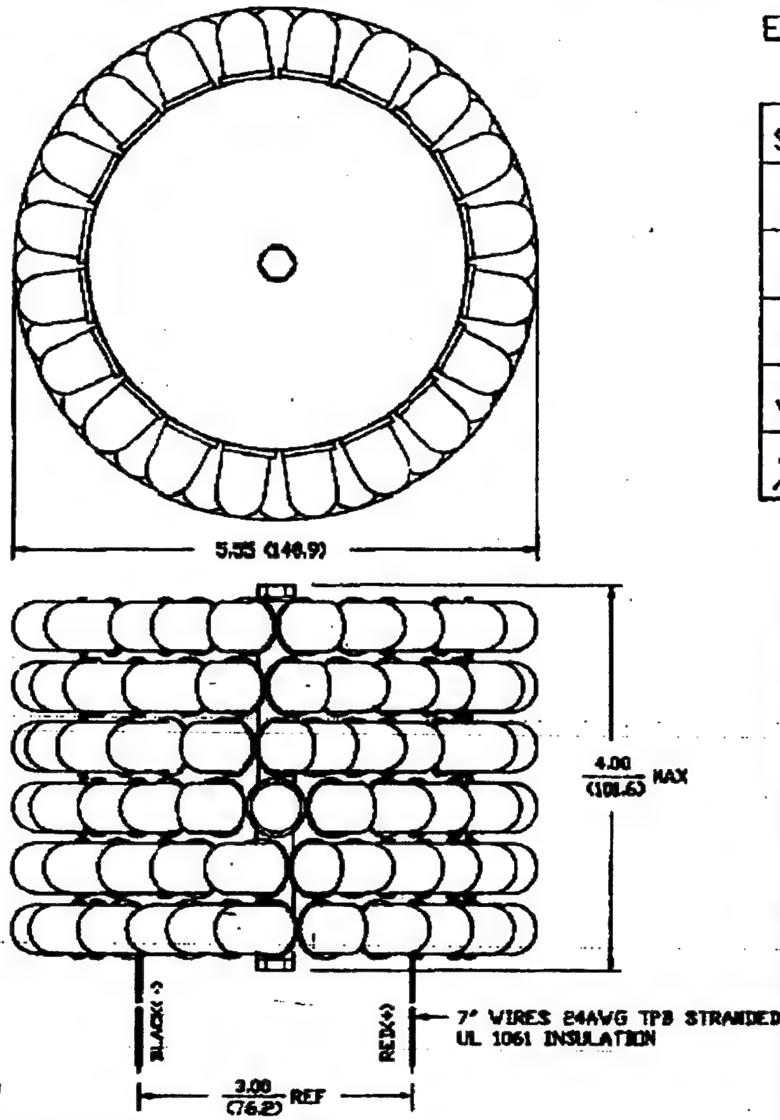
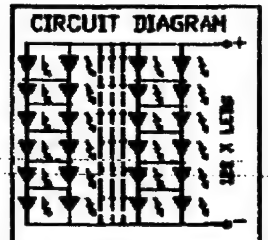


ELECTRO-OPTICAL CHARACTERISTICS @ Ta = 25°C

SYN	PARAMETER	LED COLOR: RED	GREEN	AMBER	YELLOW	ORANGE	AMB/YEL	UNIT
I_v	TYP. LUMINOUS INTENSITY PER LED @ If= 20mA	15						CD
V_F	TYP. FORWARD VOLTAGE @ If= 400mA	11.1						V
V_{FM}	MAX. FORWARD VOLTAGE @ If= 400mA	14.4						V
V_{BR}	REVERSE BREAKDOWN @ Ir= 100uA	30						V
λ_{pk}	PEAK WAVELENGTH	650						nm



ABSOLUTE MAX. RATINGS Ta=25°C

PARAMETER	VALUE	UNIT
POWER DISSIPATION	2,000	mW
DERATE/°C >Ta	28	mW
PEAK FORWARD CURRENT	4,000	mA
FORWARD CURRENT	1,000	mA
OPERATING TEMPERATURE	-55<+100	°C
STORAGE TEMPERATURE	-55<+100	°C

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DATE:	DWN BY:	CHK'D BY:
940124	NN	[illegible]
LAST REV. DATE: —	REV LEVEL —	MATERIAL —

TITLE SP940114

SCALE:	TOL:	XX(.X)	XXX(.XX)	ANG.	DWG NUMBER:
NONE	±	.025(.63)	.010(.25)	—	SP940114

REMARKS:

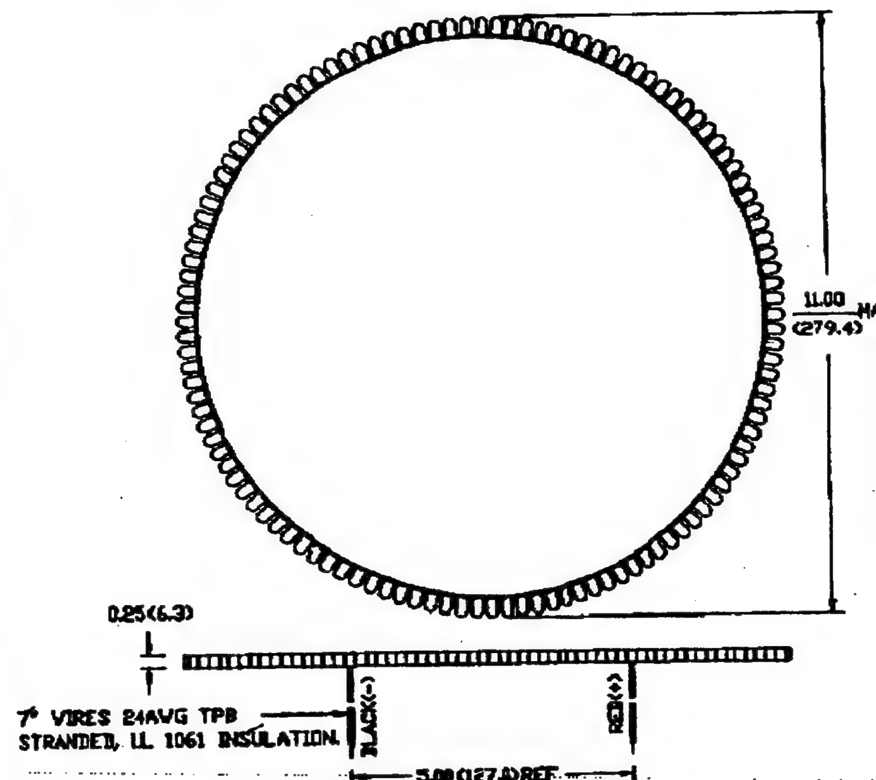
1. LEDs encapsulation is water-clear.
2. ~~Dimensions are in inches(mm).~~
3. This device must be used with series external resistor.

REV.	DATE	BY	DESCRIPTION
-	940124	NN	PRELIMINARY ONLY

SP940115

ELECTRO-OPTICAL CHARACTERISTICS @ Ta = 25°C

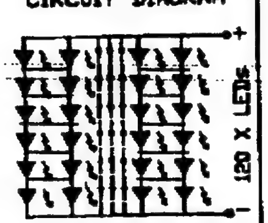
SYM	PARAMETER	LED COLOR: RED	ORANGE	AMBER	GREEN	P GRN		UNIT
I_v	TYP. LUMINOUS INTENSITY PER LED @ IF= 20mA	3,000						mcd
V_f	TYP. FORWARD VOLTAGE @ IF= 400mA	11.1						V
V_{fm}	MAX. FORWARD VOLTAGE @ IF= 400mA	14.4						V
V_{br}	REVERSE BREAKDOWN @ Ir= 100uA	30						V
λ_{pk}	PEAK WAVELENGTH	654						nm



ABSOLUTE MAX. RATINGS Ta=25°C

PARAMETER	VALUE	UNIT
POWER DISSIPATION	2,000	mW
DERATE/°C >Ta	28	mW
PEAK FORWARD CURRENT	6,000	mA
FORWARD CURRENT	1,000	mA
OPERATING TEMPERATURE	-55(+100	°C
STORAGE TEMPERATURE	-55(+100	°C

CIRCUIT DIAGRAM



REMARKS:
1. Dimensions are in inches(mm).
2. LEDs encapsulation is water-clear.
3. This device must be used with series external resistor.

Data Display Products
445 SOUTH DOUGLAS STREET, EL SEGUNDO, CA 90245 (310)640-0442 FAX: (310)640-7639

DATE: 940124	DWN BY: NN	CHK'D BY: NN
LAST REV. DATE: -	REV LEVEL: -	MATERIAL: -

TITLE: SP940115

SCALE:	TOL:	.XX(.X)	.XXX(.XX)	ANG.	DWG NUMBER:
NONE	±	.025(.63)	.010(.25)	-	SP940115

APPENDIX C
T-4 Prototype System
Photometric Data

HORIZONTAL INTENSITIES

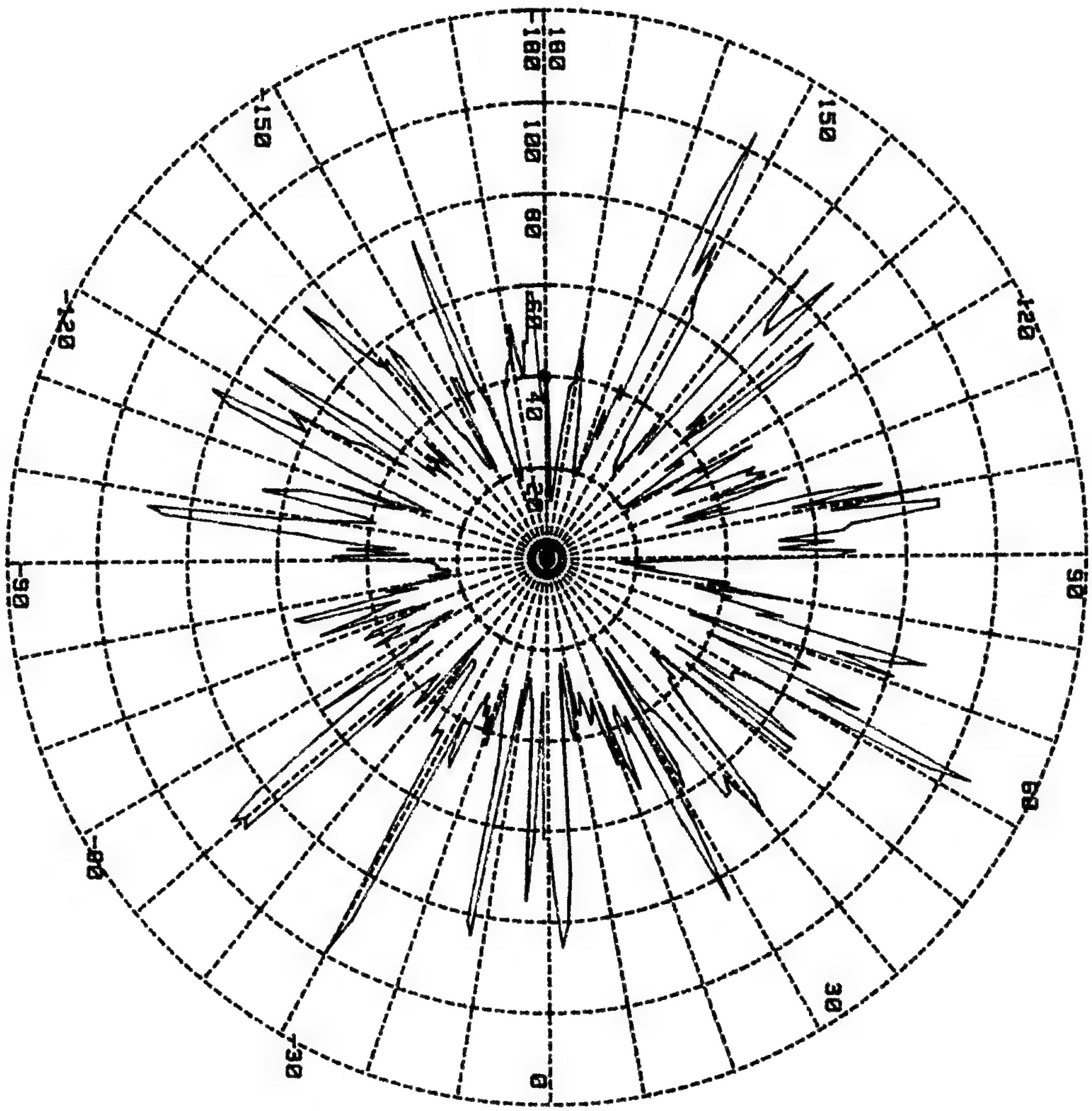
LANTERN = LED 120 HP T-4
LAMP = HP. T-4 LED
POWER SUPPLY READINGS: 12.00 VDC   CURRENT = .850 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 24 May 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-180.00	.03494	42.64	0.00	.05059	61.72
-179.00	.02798	34.14	1.00	.06071	74.07
-178.00	.03010	36.73	2.00	.07002	85.44
-177.00	.04785	58.39	3.00	.06617	80.73
-176.00	.04806	58.64	4.00	.05688	69.40
-175.00	.03900	47.59	5.00	.03064	37.38
-174.00	.03913	47.74	6.00	.02109	25.74
-173.00	.03276	39.97	7.00	.01917	23.39
-172.00	.03581	43.70	8.00	.03130	38.19
-171.00	.04236	51.69	9.00	.03302	40.29
-170.00	.03623	44.20	10.00	.02113	25.78
-169.00	.03596	43.87	11.00	.02834	34.57
-168.00	.03473	42.37	12.00	.02859	34.88
-167.00	.03196	38.99	13.00	.02480	30.25
-166.00	.03185	38.85	14.00	.02659	32.44
-165.00	.02353	28.71	15.00	.03074	37.51
-164.00	.01625	19.83	16.00	.02958	36.09
-163.00	.01486	18.13	17.00	.02645	32.27
-162.00	.01524	18.59	18.00	.03279	40.01
-161.00	.01702	20.77	19.00	.03915	47.77
-160.00	.02107	25.71	20.00	.02822	34.44
-159.00	.03111	37.96	21.00	.03985	48.63
-158.00	.03417	41.69	22.00	.04466	54.49
-157.00	.06204	75.69	23.00	.03106	37.89
-156.00	.05013	61.16	24.00	.02913	35.55
-155.00	.03608	44.02	25.00	.03475	42.40
-154.00	.02950	35.99	26.00	.03180	38.80
-153.00	.03629	44.28	27.00	.05399	65.87
-152.00	.03682	44.92	28.00	.07004	85.46
-151.00	.01889	23.05	29.00	.05340	65.15
-150.00	.02577	31.44	30.00	.02121	25.88
-149.00	.01931	23.56	31.00	.04811	58.71
-148.00	.01935	23.61	32.00	.04373	53.35
-147.00	.02049	25.00	33.00	.01936	23.62
-146.00	.02632	32.12	34.00	.03083	37.62
-145.00	.02868	35.00	35.00	.03342	40.77
-144.00	.04501	54.92	36.00	.03734	45.56
-143.00	.04802	58.59	37.00	.05404	65.93
-142.00	.03396	41.44	38.00	.05363	65.43
-141.00	.04607	56.21	39.00	.05067	61.82
-140.00	.04514	55.07	40.00	.06047	73.78
-139.00	.04653	56.77	41.00	.05693	69.46
-138.00	.05049	61.60	42.00	.04668	56.95
-137.00	.05798	70.74	43.00	.03812	46.51

-136.00	.06325	77.17	44.00	.03441	41.99
-135.00	.02162	26.38	45.00	.03122	38.09
-134.00	.03053	37.25	46.00	.03086	37.65
-133.00	.02459	30.01	47.00	.03143	38.34
-132.00	.02605	31.78	48.00	.02532	30.89
-131.00	.02855	34.84	49.00	.02661	32.47
-130.00	.02375	28.98	50.00	.03254	39.70
-129.00	.02568	31.33	51.00	.05588	68.18
-128.00	.02745	33.49	52.00	.05605	68.39
-127.00	.02538	30.97	53.00	.03152	38.46
-126.00	.04273	52.14	54.00	.05560	67.84
-125.00	.05220	63.69	55.00	.04917	60.00
-124.00	.06172	75.30	56.00	.02819	34.39
-123.00	.03014	36.78	57.00	.04037	49.26
-122.00	.03894	47.51	58.00	.03953	48.23
-121.00	.04130	50.39	59.00	.03975	48.50
-120.00	.05355	65.34	60.00	.04492	54.81
-119.00	.05122	62.49	61.00	.07839	95.64
-118.00	.04966	60.59	62.00	.08690	106.02
-117.00	.06814	83.14	63.00	.05276	64.38
-116.00	.06387	77.93	64.00	.06280	76.62
-115.00	.04785	58.38	65.00	.03207	39.13
-114.00	.03768	45.98	66.00	.04181	51.02
-113.00	.02779	33.90	67.00	.05184	63.25
-112.00	.02272	27.72	68.00	.04704	57.40
-111.00	.02544	31.04	69.00	.02778	33.90
-110.00	.03905	47.65	70.00	.03122	38.09
-109.00	.02791	34.05	71.00	.06661	81.27
-108.00	.03096	37.78	72.00	.05539	67.58
-107.00	.03760	45.88	73.00	.06561	80.06
-106.00	.04648	56.71	74.00	.07151	87.25
-105.00	.04887	59.62	75.00	.03933	47.99
-104.00	.05330	65.03	76.00	.04409	53.80
-103.00	.03385	41.31	77.00	.03274	39.94
-102.00	.03186	38.87	78.00	.03415	41.67
-101.00	.03625	44.23	79.00	.02740	33.42
-100.00	.04079	49.77	80.00	.04398	53.66
-99.00	.04926	60.10	81.00	.02962	36.14
-98.00	.07343	89.59	82.00	.03341	40.77
-97.00	.06988	85.27	83.00	.02081	25.39
-96.00	.04548	55.49	84.00	.01615	19.70
-95.00	.03818	46.58	85.00	.01962	23.94
-94.00	.02771	33.81	86.00	.01419	17.32
-93.00	.03646	44.49	87.00	.01257	15.34
-92.00	.02530	30.86	88.00	.01818	22.19
-91.00	.03915	47.77	89.00	.02249	27.44
-90.00	.03581	43.69	90.00	.05255	64.12
-89.00	.02251	27.46	91.00	.05608	68.42
-88.00	.02054	25.06	92.00	.04233	51.64
-87.00	.02021	24.66	93.00	.05226	63.76
-86.00	.01978	24.13	94.00	.04233	51.65
-85.00	.02021	24.66	95.00	.05436	66.33
-84.00	.01818	22.19	96.00	.05599	68.31
-83.00	.01781	21.73	97.00	.07207	87.94
-82.00	.02177	26.56	98.00	.07209	87.96
-81.00	.01774	21.64	99.00	.05249	64.05
-80.00	.02331	28.44	100.00	.06877	83.90
-79.00	.02981	36.37	101.00	.04565	55.69
-78.00	.02410	29.41	102.00	.06241	76.14
-77.00	.04728	57.68	103.00	.05121	62.48

-76.00	.04551	55.53	104.00	.02247	27.42
-75.00	.02786	33.99	105.00	.03442	41.99
-74.00	.03178	38.77	106.00	.02588	31.58
-73.00	.03477	42.42	107.00	.03619	44.16
-72.00	.04341	52.96	108.00	.04591	56.02
-71.00	.02585	31.54	109.00	.03158	38.53
-70.00	.02414	29.46	110.00	.04010	48.92
-69.00	.02385	29.10	111.00	.04239	51.72
-68.00	.03431	41.87	112.00	.03938	48.04
-67.00	.03609	44.04	113.00	.04102	50.04
-66.00	.02851	34.78	114.00	.03181	38.81
-65.00	.03009	36.71	115.00	.02863	34.93
-64.00	.03508	42.81	116.00	.02566	31.30
-63.00	.02715	33.12	117.00	.03328	40.60
-62.00	.01956	23.87	118.00	.04234	51.66
-61.00	.02420	29.53	119.00	.03158	38.54
-60.00	.02579	31.46	120.00	.03157	38.52
-59.00	.02804	34.22	121.00	.02302	28.09
-58.00	.03112	37.97	122.00	.01752	21.38
-57.00	.04875	59.49	123.00	.01659	20.24
-56.00	.03667	44.74	124.00	.03006	36.68
-55.00	.02556	31.18	125.00	.03007	36.69
-54.00	.03930	47.95	126.00	.02682	32.72
-53.00	.05159	62.95	127.00	.05672	69.21
-52.00	.06744	82.29	128.00	.06182	75.42
-51.00	.07441	90.79	129.00	.03620	44.17
-50.00	.07207	87.94	130.00	.03194	38.97
-49.00	.07334	89.48	131.00	.03807	46.45
-48.00	.03566	43.51	132.00	.03451	42.11
-47.00	.04350	53.07	133.00	.07174	87.53
-46.00	.03306	40.34	134.00	.06367	77.68
-45.00	.03057	37.29	135.00	.05636	68.77
-44.00	.02859	34.88	136.00	.05874	71.67
-43.00	.03578	43.66	137.00	.06998	85.38
-42.00	.03365	41.05	138.00	.02509	30.61
-41.00	.02173	26.51	139.00	.03116	38.02
-40.00	.01972	24.06	140.00	.02970	36.24
-39.00	.02716	33.14	141.00	.02192	26.75
-38.00	.03657	44.61	142.00	.01988	24.25
-37.00	.02252	27.48	143.00	.02070	25.25
-36.00	.02237	27.29	144.00	.02174	26.53
-35.00	.02342	28.58	145.00	.02452	29.91
-34.00	.03801	46.38	146.00	.02552	31.14
-33.00	.03665	44.71	147.00	.03303	40.30
-32.00	.03617	44.13	148.00	.05066	61.81
-31.00	.05198	63.42	149.00	.05193	63.36
-30.00	.08029	97.96	150.00	.05612	68.47
-29.00	.07430	90.65	151.00	.06423	78.37
-28.00	.03226	39.37	152.00	.05744	70.08
-27.00	.03993	48.72	153.00	.08521	103.97
-26.00	.04143	50.55	154.00	.07315	89.25
-25.00	.02877	35.10	155.00	.03129	38.17
-24.00	.02634	32.14	156.00	.03370	41.12
-23.00	.03034	37.01	157.00	.02336	28.50
-22.00	.02851	34.78	158.00	.02843	34.69
-21.00	.03328	40.61	159.00	.01992	24.31
-20.00	.03005	36.67	160.00	.01708	20.83
-19.00	.03522	42.97	161.00	.01590	19.39
-18.00	.02371	28.92	162.00	.01555	18.97
-17.00	.02774	33.84	163.00	.01702	20.76

-16.00	.03106	37.90	164.00	.01876	22.89
-15.00	.03340	40.75	165.00	.02105	25.68
-14.00	.03857	47.07	166.00	.02361	28.81
-13.00	.06694	81.67	167.00	.02697	32.91
-12.00	.06914	84.36	168.00	.03015	36.79
-11.00	.02393	29.20	169.00	.03455	42.16
-10.00	.03035	37.03	170.00	.03840	46.86
-9.00	.02325	28.37	171.00	.03194	38.97
-8.00	.02169	26.46	172.00	.03115	38.01
-7.00	.02514	30.67	173.00	.02408	29.38
-6.00	.02552	31.14	174.00	.01744	21.28
-5.00	.03875	47.28	175.00	.01261	15.39
-4.00	.06180	75.40	176.00	.01048	12.79
-3.00	.05136	62.66	177.00	.01081	13.19
-2.00	.02408	29.38	178.00	.01402	17.10
-1.00	.05055	61.68	179.00	.02341	28.56
0.00	.05059	61.72	180.00	.03265	39.84



POLAR PLOT OF
HORIZONTAL INTENSITIES
LED 120 HP T-4
HP, T-4 LED
MAXIMUM INTENSITY: 106.02 MINIMUM INTENSITY: 12.79
MEAN HORIZONTAL INTENSITY: 45.41

VERTICAL INTENSITIES
MEASURED THROUGH HORIZONTAL DEGREE. 62

LANTERN = LED 120 HP T-4
LAMP = HP, T-4 LED
POWER SUPPLY READINGS: 12.00 VDC CURRENT = .850 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 24 May 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-4.00	.01515	18.49	0.00	.07974	97.29
-3.90	.01560	19.03	.10	.08117	99.03
-3.80	.01602	19.55	.20	.08277	100.99
-3.70	.01651	20.15	.30	.08369	102.10
-3.60	.01704	20.79	.40	.08425	102.79
-3.50	.01761	21.48	.50	.08370	102.12
-3.40	.01823	22.24	.60	.08268	100.88
-3.30	.01883	22.97	.70	.08082	98.61
-3.20	.01953	23.83	.80	.07685	93.76
-3.10	.02029	24.76	.90	.07129	86.98
-3.00	.02123	25.90	1.00	.06358	77.57
-2.90	.02232	27.24	1.10	.05579	68.07
-2.80	.02384	29.08	1.20	.04729	57.70
-2.70	.02592	31.63	1.30	.04213	51.40
-2.60	.02811	34.30	1.40	.03799	46.36
-2.50	.03023	36.88	1.50	.03573	43.59
-2.40	.03174	38.72	1.60	.03397	41.45
-2.30	.03261	39.78	1.70	.03297	40.23
-2.20	.03303	40.30	1.80	.03256	39.72
-2.10	.03357	40.96	1.90	.03356	40.95
-2.00	.03398	41.46	2.00	.03502	42.73
-1.90	.03359	40.99	2.10	.03670	44.78
-1.80	.03295	40.21	2.20	.03901	47.60
-1.70	.03255	39.71	2.30	.04192	51.15
-1.60	.03260	39.78	2.40	.04439	54.17
-1.50	.03356	40.95	2.50	.04586	55.95
-1.40	.03531	43.08	2.60	.04580	55.88
-1.30	.03797	46.32	2.70	.04495	54.84
-1.20	.04206	51.32	2.80	.04387	53.53
-1.10	.04689	57.21	2.90	.04144	50.57
-1.00	.05227	63.77	3.00	.03917	47.79
-.90	.05801	70.78	3.10	.03667	44.74
-.80	.06306	76.94	3.20	.03428	41.82
-.70	.06722	82.02	3.30	.03209	39.16
-.60	.07039	85.88	3.40	.03023	36.89
-.50	.07366	89.88	3.50	.02858	34.87
-.40	.07505	91.57	3.60	.02713	33.10
-.30	.07621	92.99	3.70	.02601	31.74
-.20	.07743	94.47	3.80	.02454	29.94
-.10	.07887	96.23	3.90	.02352	28.69
0.00	.07974	97.29	4.00	.02229	27.20

VERTICAL INTENSITIES
MEASURED THROUGH HORIZONTAL DEGREE. 86

LANTERN = LED 120 HP T-4
LAMP = HP. T-4 LED
POWER SUPPLY READINGS: 12.00 VDC CURRENT = .850 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 24 May 1994
OPERATOR IS Bruce Roberts

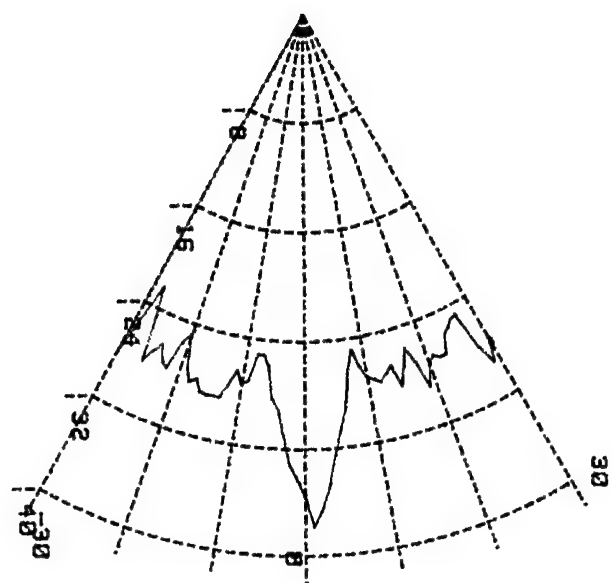
DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-4.00	.00726	8.86	0.00	.01292	15.77
-3.90	.00734	8.95	.10	.01308	15.95
-3.80	.00743	9.07	.20	.01319	16.09
-3.70	.00753	9.19	.30	.01315	16.05
-3.60	.00761	9.29	.40	.01316	16.05
-3.50	.00771	9.40	.50	.01315	16.04
-3.40	.00781	9.53	.60	.01313	16.02
-3.30	.00792	9.66	.70	.01310	15.98
-3.20	.00804	9.80	.80	.01304	15.92
-3.10	.00814	9.93	.90	.01301	15.88
-3.00	.00826	10.07	1.00	.01295	15.80
-2.90	.00836	10.20	1.10	.01298	15.84
-2.80	.00849	10.36	1.20	.01297	15.83
-2.70	.00861	10.51	1.30	.01301	15.88
-2.60	.00873	10.65	1.40	.01299	15.85
-2.50	.00885	10.80	1.50	.01290	15.74
-2.40	.00896	10.93	1.60	.01281	15.62
-2.30	.00906	11.05	1.70	.01275	15.56
-2.20	.00917	11.19	1.80	.01270	15.50
-2.10	.00929	11.33	1.90	.01265	15.43
-2.00	.00940	11.47	2.00	.01260	15.38
-1.90	.00955	11.66	2.10	.01259	15.37
-1.80	.00977	11.92	2.20	.01252	15.27
-1.70	.00998	12.18	2.30	.01241	15.14
-1.60	.01017	12.41	2.40	.01228	14.98
-1.50	.01040	12.69	2.50	.01218	14.86
-1.40	.01058	12.91	2.60	.01208	14.74
-1.30	.01077	13.15	2.70	.01198	14.61
-1.20	.01098	13.40	2.80	.01187	14.48
-1.10	.01122	13.69	2.90	.01176	14.35
-1.00	.01147	14.00	3.00	.01162	14.18
-.90	.01172	14.30	3.10	.01150	14.03
-.80	.01199	14.63	3.20	.01141	13.92
-.70	.01204	14.69	3.30	.01127	13.75
-.60	.01203	14.67	3.40	.01110	13.54
-.50	.01209	14.76	3.50	.01095	13.36
-.40	.01246	15.21	3.60	.01077	13.13
-.30	.01273	15.53	3.70	.01053	12.84
-.20	.01275	15.55	3.80	.01030	12.57
-.10	.01278	15.59	3.90	.01016	12.39
0.00	.01292	15.77	4.00	.00992	12.10

APPENDIX D
T-1 3/4 Prototype System
Photometric Data

HORIZONTAL INTENSITIES

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 11.75 VDC CURRENT = .799 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-30.00	.02321	28.32	0.00	.02920	35.63
-29.00	.02063	25.18	1.00	.03099	37.81
-28.00	.01836	22.41	2.00	.03004	36.66
-27.00	.02018	24.62	3.00	.02863	34.94
-26.00	.02294	27.99	4.00	.02670	32.58
-25.00	.02215	27.02	5.00	.02524	30.80
-24.00	.02153	26.27	6.00	.02396	29.23
-23.00	.02253	27.48	7.00	.02161	26.37
-22.00	.02274	27.75	8.00	.02036	24.84
-21.00	.02097	25.59	9.00	.02147	26.20
-20.00	.02031	24.78	10.00	.02219	27.07
-19.00	.02234	27.26	11.00	.02241	27.34
-18.00	.02309	28.17	12.00	.02263	27.62
-17.00	.02280	27.82	13.00	.02224	27.14
-16.00	.02349	28.66	14.00	.02183	26.63
-15.00	.02358	28.77	15.00	.02317	28.26
-14.00	.02352	28.70	16.00	.02212	26.99
-13.00	.02355	28.73	17.00	.02103	25.66
-12.00	.02270	27.70	18.00	.02206	26.92
-11.00	.02174	26.52	19.00	.02374	28.97
-10.00	.02247	27.42	20.00	.02258	27.55
-9.00	.02226	27.15	21.00	.02203	26.88
-8.00	.02056	25.09	22.00	.02227	27.17
-7.00	.02055	25.07	23.00	.02225	27.15
-6.00	.02120	25.86	24.00	.02108	25.72
-5.00	.02317	28.27	25.00	.02082	25.41
-4.00	.02383	29.07	26.00	.02047	24.97
-3.00	.02541	31.00	27.00	.02031	24.78
-2.00	.02724	33.24	28.00	.02274	27.75
-1.00	.02806	34.23	29.00	.02401	29.30
0.00	.02920	35.63	30.00	.02280	27.82

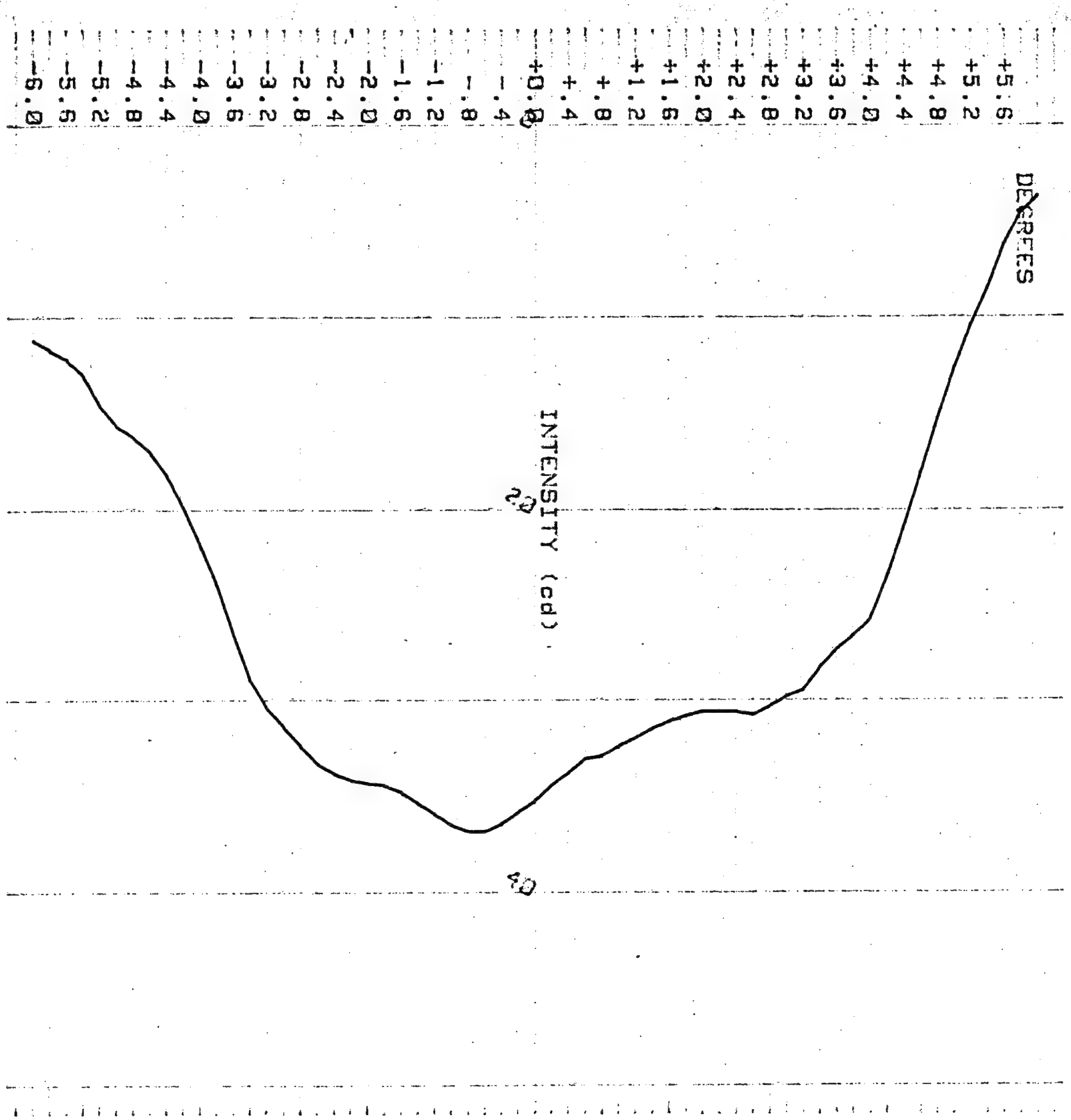


POLAR PLOT OF
HORIZONTAL INTENSITIES
Thin Film Fresnel
120 t-1 3/4 leds in circle
MAXIMUM INTENSITY: 37.81 MINIMUM INTENSITY: 22.41
MEAN HORIZONTAL INTENSITY: 28.00

VERTICAL INTENSITIES

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 11.75 VDC CURRENT = .799 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-6.00	.00922	11.24	0.00	.02894	35.31
-5.80	.00967	11.80	.20	.02826	34.48
-5.60	.01006	12.27	.40	.02773	33.84
-5.40	.01073	13.09	.60	.02715	33.12
-5.20	.01201	14.66	.80	.02701	32.95
-5.00	.01288	15.71	1.00	.02660	32.46
-4.80	.01335	16.29	1.20	.02624	32.02
-4.60	.01397	17.05	1.40	.02583	31.52
-4.40	.01497	18.26	1.60	.02554	31.16
-4.20	.01633	19.92	1.80	.02530	30.86
-4.00	.01792	21.87	2.00	.02510	30.63
-3.80	.01964	23.96	2.20	.02511	30.64
-3.60	.02176	26.55	2.40	.02514	30.67
-3.40	.02374	28.96	2.60	.02528	30.85
-3.20	.02496	30.45	2.80	.02488	30.36
-3.00	.02580	31.48	3.00	.02446	29.85
-2.80	.02661	32.46	3.20	.02418	29.51
-2.60	.02736	33.38	3.40	.02322	28.34
-2.40	.02779	33.91	3.60	.02240	27.34
-2.20	.02807	34.25	3.80	.02181	26.61
-2.00	.02821	34.42	4.00	.02111	25.75
-1.80	.02829	34.51	4.20	.01931	23.56
-1.60	.02857	34.86	4.40	.01719	20.97
-1.40	.02904	35.43	4.60	.01488	18.15
-1.20	.02950	35.99	4.80	.01258	15.35
-1.00	.02998	36.58	5.00	.01045	12.75
-.80	.03026	36.92	5.20	.00860	10.49
-.60	.03026	36.92	5.40	.00702	8.57
-.40	.02990	36.48	5.60	.00515	6.29
-.20	.02941	35.89	5.80	.00379	4.63
0.00	.02894	35.31	6.00	.00308	3.76



PLOT OF
VERTICAL INTENSITIES
MEASURED AT HORIZONTAL DEG. 2
Thin Film Fresnel
120 t-1 3/4 leds in circle

EFFECTIVE INTENSITIES (E.I.) FOR SELECT RPM
USING SCHMIDT-CLAUSEN METHOD

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 11.75 VDC CURRENT = .799 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

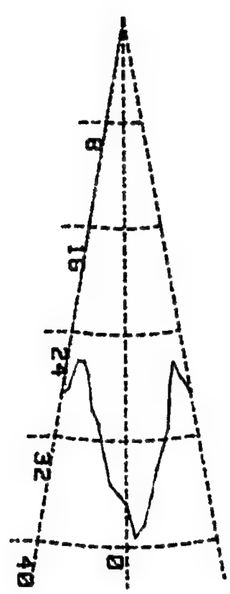
PEAK INTENSITY = 37.81 CANDELLA
BEAM WIDTH AT 5% OF PEAK = 60.00
SHAPE (FORM) FACTOR = .74061436

RPM OF 00.7 PRODUCES E.I. OF	37 Candela
RPM OF 01.0 PRODUCES E.I. OF	37 Candela
RPM OF 02.0 PRODUCES E.I. OF	36 Candela
RPM OF 03.0 PRODUCES E.I. OF	35 Candela
RPM OF 04.0 PRODUCES E.I. OF	34 Candela
RPM OF 05.0 PRODUCES E.I. OF	33 Candela
RPM OF 06.0 PRODUCES E.I. OF	32 Candela
RPM OF 07.0 PRODUCES E.I. OF	32 Candela
RPM OF 08.0 PRODUCES E.I. OF	31 Candela
RPM OF 09.0 PRODUCES E.I. OF	30 Candela
RPM OF 10.0 PRODUCES E.I. OF	29 Candela
RPM OF 11.0 PRODUCES E.I. OF	29 Candela
RPM OF 12.0 PRODUCES E.I. OF	28 Candela
RPM OF 13.0 PRODUCES E.I. OF	28 Candela
RPM OF 14.0 PRODUCES E.I. OF	27 Candela
RPM OF 15.0 PRODUCES E.I. OF	27 Candela

HORIZONTAL INTENSITIES

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 12.00 VDC CURRENT = .944 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-10.00	.02356	28.75	0.00	.03014	36.77
-9.00	.02323	28.34	1.00	.03220	39.29
-8.00	.02141	26.13	2.00	.03153	38.47
-7.00	.02139	26.10	3.00	.02979	36.35
-6.00	.02226	27.16	4.00	.02798	34.14
-5.00	.02439	29.75	5.00	.02675	32.63
-4.00	.02517	30.71	6.00	.02559	31.22
-3.00	.02703	32.98	7.00	.02287	27.91
-2.00	.02894	35.31	8.00	.02155	26.30
-1.00	.02953	36.03	9.00	.02263	27.62
0.00	.03014	36.77	10.00	.02345	28.61

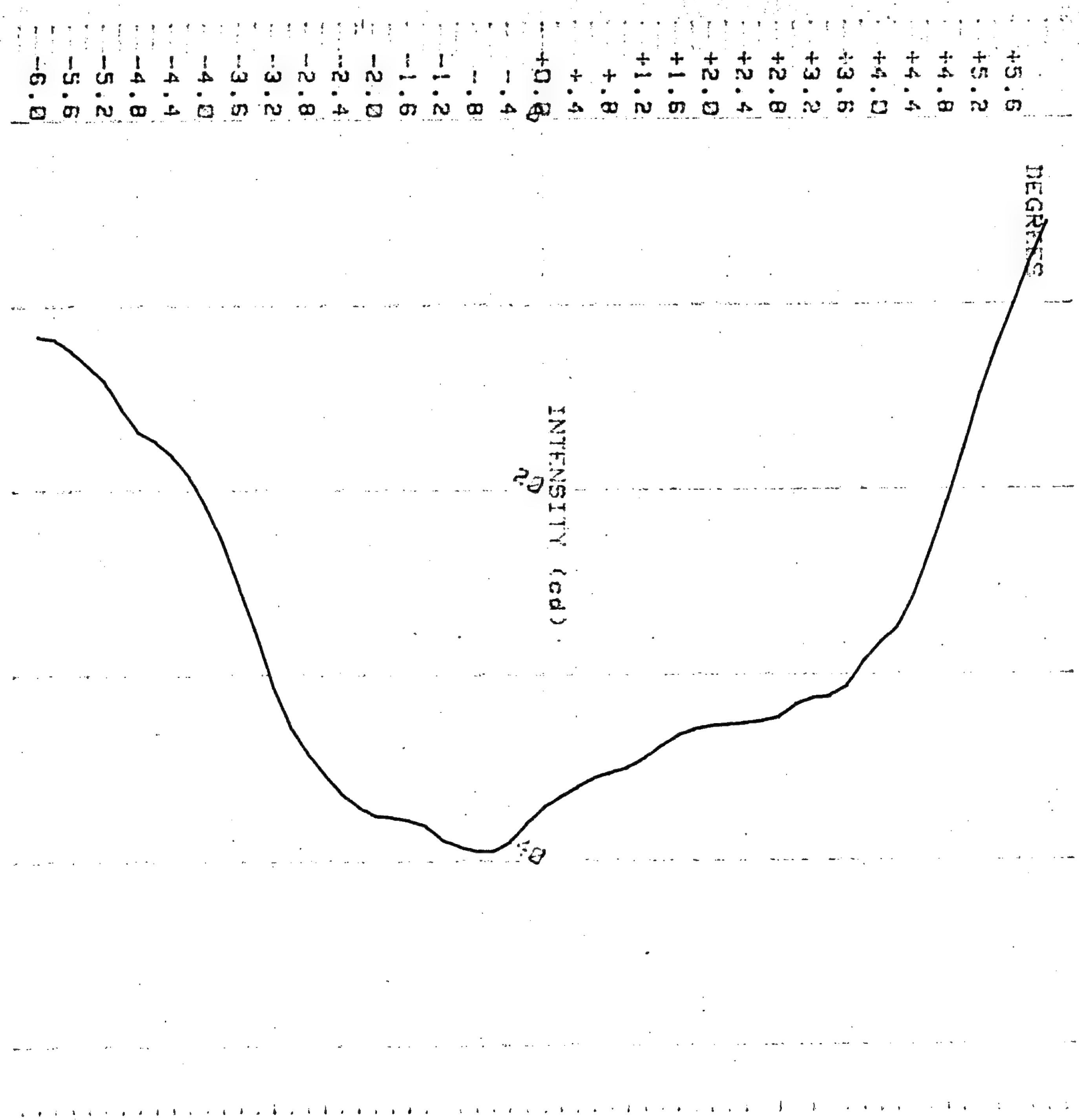


POLAR PLOT OF
HORIZONTAL INTENSITIES
Thin Film Fresnel
120 t-1 3/4 leds in circle
MAXIMUM INTENSITY: 39.29 MINIMUM INTENSITY: 26.10
MEAN HORIZONTAL INTENSITY: 31.46

VERTICAL INTENSITIES

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 12.00 VDC CURRENT = .944 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-6.00	.00958	11.69	0.00	.03047	37.18
-5.80	.00972	11.87	.20	.03001	36.62
-5.60	.01024	12.49	.40	.02958	36.08
-5.40	.01089	13.28	.60	.02917	35.59
-5.20	.01159	14.14	.80	.02894	35.31
-5.00	.01278	15.59	1.00	.02873	35.05
-4.80	.01383	16.88	1.20	.02832	34.55
-4.60	.01425	17.38	1.40	.02778	33.90
-4.40	.01490	18.18	1.60	.02730	33.31
-4.20	.01580	19.28	1.80	.02702	32.97
-4.00	.01714	20.91	2.00	.02688	32.80
-3.80	.01875	22.88	2.20	.02682	32.73
-3.60	.02080	25.38	2.40	.02676	32.65
-3.40	.02285	27.88	2.60	.02667	32.54
-3.20	.02517	30.70	2.80	.02650	32.34
-3.00	.02692	32.84	3.00	.02596	31.67
-2.80	.02807	34.25	3.20	.02565	31.30
-2.60	.02900	35.38	3.40	.02557	31.19
-2.40	.02985	36.42	3.60	.02514	30.67
-2.20	.03044	37.14	3.80	.02406	29.36
-2.00	.03083	37.61	4.00	.02321	28.32
-1.80	.03091	37.72	4.20	.02257	27.54
-1.60	.03104	37.87	4.40	.02118	25.84
-1.40	.03130	38.19	4.60	.01919	23.41
-1.20	.03190	38.93	4.80	.01707	20.83
-1.00	.03220	39.28	5.00	.01473	17.98
-.80	.03241	39.54	5.20	.01224	14.93
-.60	.03240	39.53	5.40	.01012	12.35
-.40	.03198	39.02	5.60	.00830	10.13
-.20	.03117	38.04	5.80	.00634	7.73
0.00	.03047	37.18	6.00	.00465	5.68

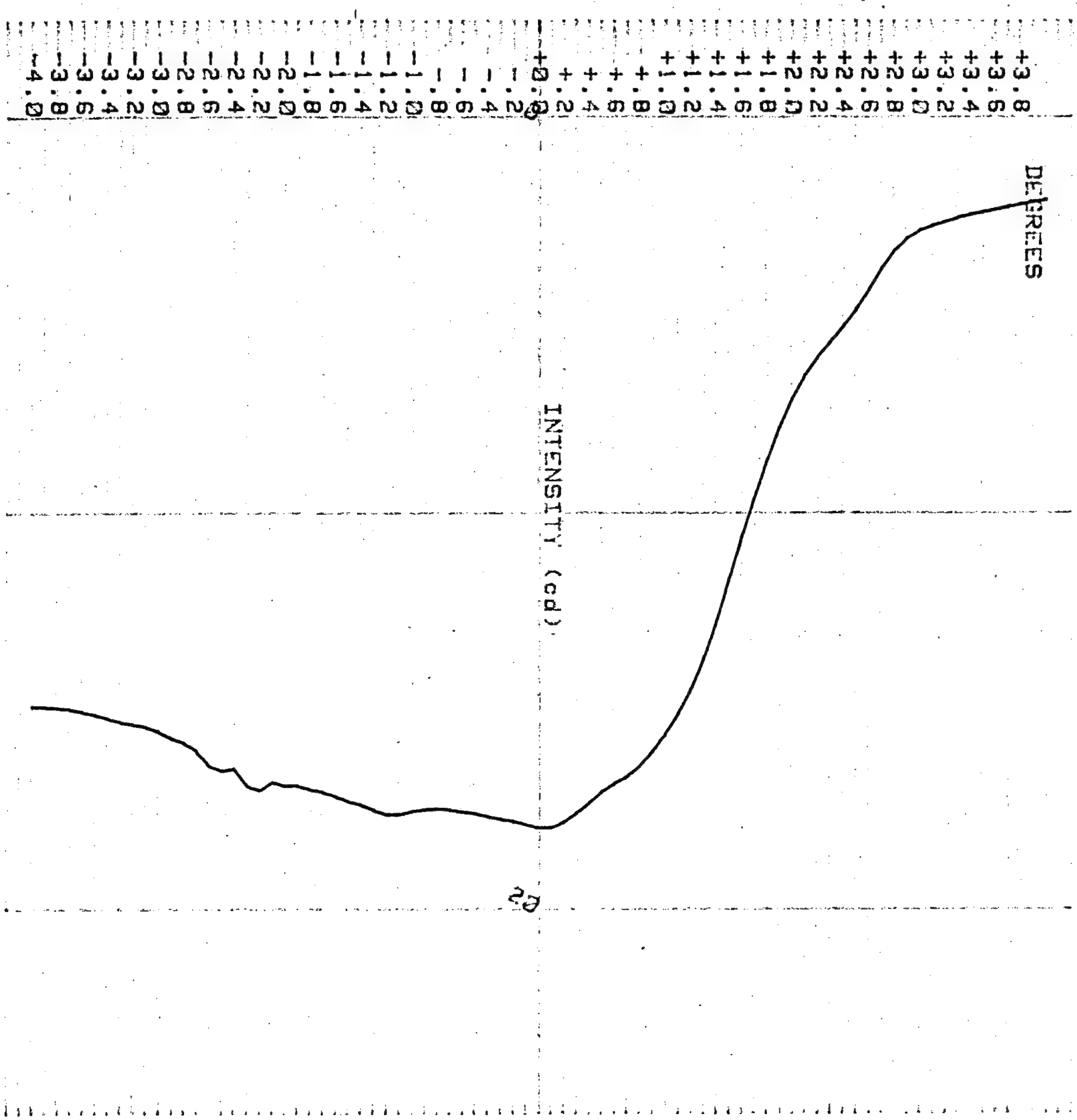


PLOT OF
VERTICAL INTENSITIES
MEASURED AT HORIZONTAL DEG. 2
Thin Film Fresnel
120 t-1 3/4 leds in circle

VERTICAL INTENSITIES
MEASURED THROUGH HORIZONTAL DEGREE, 0

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 10.95 VDC CURRENT = .400 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-4.00	.01222	14.91	0.00	.01475	17.99
-3.90	.01224	14.93	.10	.01474	17.98
-3.80	.01226	14.96	.20	.01461	17.83
-3.70	.01229	14.99	.30	.01443	17.61
-3.60	.01235	15.06	.40	.01422	17.35
-3.50	.01240	15.13	.50	.01399	17.06
-3.40	.01248	15.22	.60	.01381	16.86
-3.30	.01256	15.32	.70	.01366	16.67
-3.20	.01260	15.38	.80	.01344	16.40
-3.10	.01266	15.44	.90	.01315	16.05
-3.00	.01276	15.56	1.00	.01279	15.61
-2.90	.01289	15.72	1.10	.01237	15.09
-2.80	.01298	15.84	1.20	.01187	14.48
-2.70	.01315	16.04	1.30	.01125	13.72
-2.60	.01344	16.40	1.40	.01048	12.79
-2.50	.01355	16.54	1.50	.00960	11.71
-2.40	.01349	16.46	1.60	.00873	10.65
-2.30	.01387	16.92	1.70	.00791	9.65
-2.20	.01396	17.04	1.80	.00713	8.70
-2.10	.01378	16.82	1.90	.00643	7.84
-2.00	.01387	16.93	2.00	.00584	7.13
-1.90	.01386	16.91	2.10	.00534	6.52
-1.80	.01395	17.01	2.20	.00496	6.06
-1.70	.01400	17.08	2.30	.00465	5.67
-1.60	.01409	17.19	2.40	.00433	5.28
-1.50	.01419	17.31	2.50	.00398	4.85
-1.40	.01426	17.40	2.60	.00357	4.36
-1.30	.01437	17.53	2.70	.00314	3.83
-1.20	.01446	17.65	2.80	.00278	3.39
-1.10	.01445	17.63	2.90	.00252	3.08
-1.00	.01438	17.55	3.00	.00236	2.88
-.90	.01434	17.50	3.10	.00226	2.76
-.80	.01433	17.48	3.20	.00218	2.66
-.70	.01436	17.53	3.30	.00210	2.56
-.60	.01441	17.58	3.40	.00203	2.48
-.50	.01445	17.63	3.50	.00198	2.42
-.40	.01451	17.70	3.60	.00193	2.35
-.30	.01456	17.77	3.70	.00187	2.28
-.20	.01461	17.82	3.80	.00182	2.22
-.10	.01468	17.91	3.90	.00177	2.16
0.00	.01475	17.99	4.00	.00173	2.11

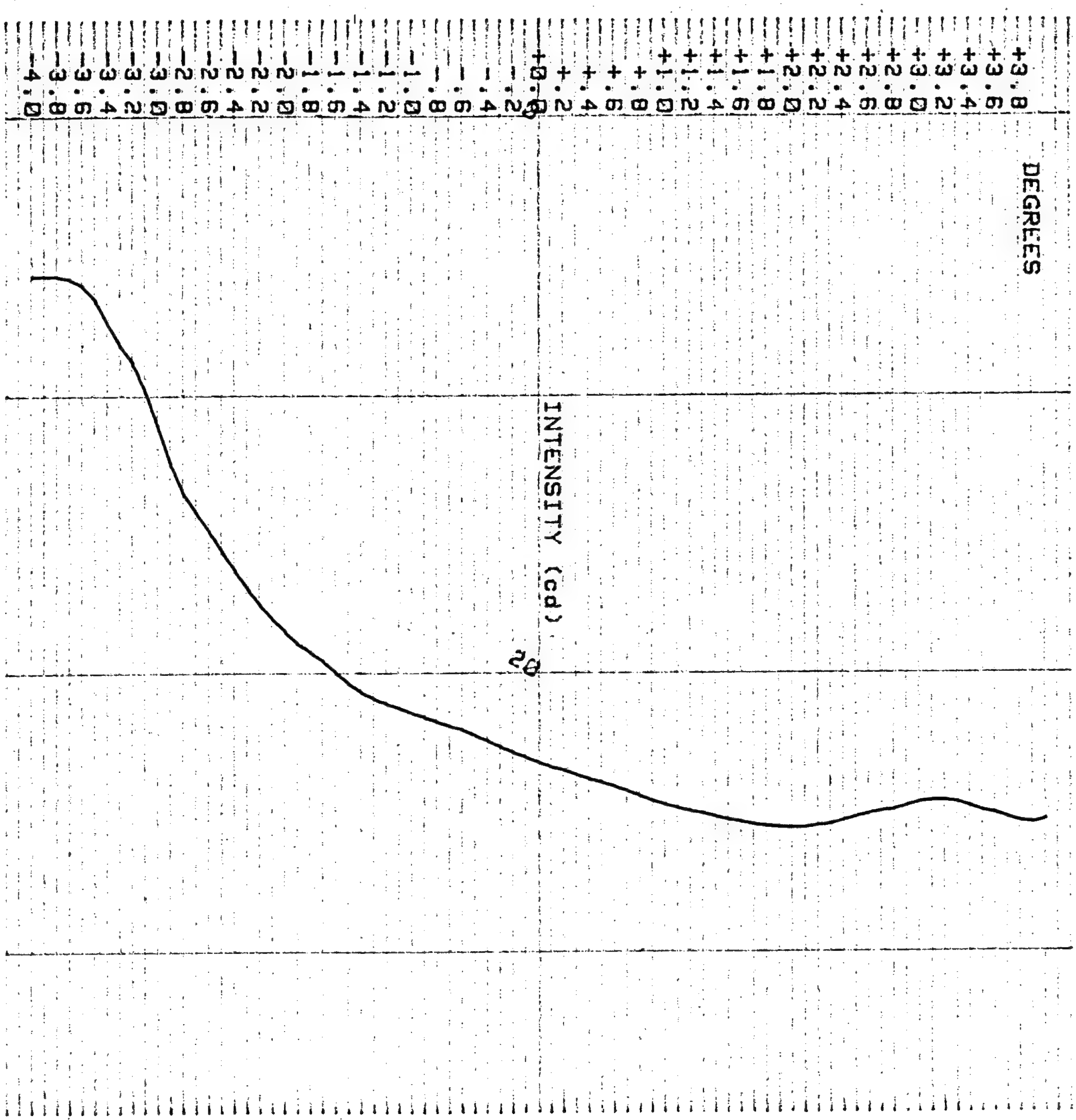


PLOT OF
VERTICAL INTENSITIES
MEASURED AT HORIZONTAL DEG. 0
Thin Film Fresnel
120 t-1 3/4 leds in circle

VERTICAL INTENSITIES
MEASURED THROUGH HORIZONTAL DEGREE. 100

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 10.95 VDC CURRENT = .400 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-4.00	.00468	5.72	0.00	.01903	23.22
-3.90	.00470	5.73	.10	.01917	23.39
-3.80	.00472	5.75	.20	.01925	23.49
-3.70	.00480	5.86	.30	.01939	23.66
-3.60	.00500	6.10	.40	.01952	23.81
-3.50	.00541	6.60	.50	.01962	23.94
-3.40	.00610	7.44	.60	.01973	24.07
-3.30	.00673	8.21	.70	.01987	24.24
-3.20	.00725	8.85	.80	.02001	24.41
-3.10	.00809	9.87	.90	.02015	24.59
-3.00	.00914	11.15	1.00	.02026	24.71
-2.90	.01024	12.49	1.10	.02036	24.84
-2.80	.01110	13.55	1.20	.02045	24.95
-2.70	.01168	14.25	1.30	.02051	25.03
-2.60	.01222	14.91	1.40	.02062	25.16
-2.50	.01283	15.65	1.50	.02071	25.27
-2.40	.01339	16.34	1.60	.02076	25.33
-2.30	.01394	17.00	1.70	.02084	25.43
-2.20	.01442	17.60	1.80	.02089	25.49
-2.10	.01483	18.09	1.90	.02091	25.52
-2.00	.01521	18.56	2.00	.02093	25.54
-1.90	.01557	18.99	2.10	.02090	25.49
-1.80	.01582	19.30	2.20	.02084	25.42
-1.70	.01608	19.61	2.30	.02079	25.37
-1.60	.01641	20.02	2.40	.02070	25.25
-1.50	.01672	20.40	2.50	.02059	25.13
-1.40	.01698	20.72	2.60	.02050	25.01
-1.30	.01718	20.96	2.70	.02042	24.91
-1.20	.01732	21.14	2.80	.02038	24.86
-1.10	.01745	21.29	2.90	.02027	24.74
-1.00	.01760	21.47	3.00	.02017	24.61
-.90	.01771	21.61	3.10	.02012	24.55
-.80	.01785	21.78	3.20	.02014	24.57
-.70	.01798	21.94	3.30	.02019	24.64
-.60	.01808	22.06	3.40	.02032	24.79
-.50	.01825	22.27	3.50	.02044	24.94
-.40	.01841	22.46	3.60	.02051	25.03
-.30	.01858	22.68	3.70	.02065	25.19
-.20	.01875	22.88	3.80	.02077	25.34
-.10	.01889	23.05	3.90	.02080	25.38
0.00	.01903	23.22	4.00	.02068	25.23



PLOT OF
VERTICAL INTENSITIES
MEASURED AT HORIZONTAL DEG. 100
Thin Film Fresnel
120 t-1 3/4 leds in circle

EFFECTIVE INTENSITIES (E.I.) FOR SELECT RPM
USING SCHMIDT-CLAUSEN METHOD

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 10.95 VDC CURRENT = .400 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

PEAK INTENSITY = 23.42 CANDELLA
BEAM WIDTH AT 5% OF PEAK = 360.00
SHAPE (FORM) FACTOR = .70133906

RPM OF 00.7 PRODUCES E.I. OF 23 Candela
RPM OF 01.0 PRODUCES E.I. OF 23 Candela
RPM OF 02.0 PRODUCES E.I. OF 23 Candela
RPM OF 03.0 PRODUCES E.I. OF 23 Candela
RPM OF 04.0 PRODUCES E.I. OF 23 Candela
RPM OF 05.0 PRODUCES E.I. OF 23 Candela
RPM OF 06.0 PRODUCES E.I. OF 23 Candela
RPM OF 07.0 PRODUCES E.I. OF 23 Candela
RPM OF 08.0 PRODUCES E.I. OF 23 Candela
RPM OF 09.0 PRODUCES E.I. OF 22 Candela
RPM OF 10.0 PRODUCES E.I. OF 22 Candela
RPM OF 11.0 PRODUCES E.I. OF 22 Candela
RPM OF 12.0 PRODUCES E.I. OF 22 Candela
RPM OF 13.0 PRODUCES E.I. OF 22 Candela
RPM OF 14.0 PRODUCES E.I. OF 22 Candela
RPM OF 15.0 PRODUCES E.I. OF 22 Candela

HORIZONTAL INTENSITIES

LANTERN = Thin Film Fresnel
LAMP = 120 t-1 3/4 leds in circle
POWER SUPPLY READINGS: 10.95 VDC CURRENT = .400 AMPS
SOURCE TO DETECTOR DISTANCE = 34.93 FEET
DATE = 14 Jun 1994
OPERATOR IS Bruce Roberts

DEGREE	READING (ft cd)	INTENSITY (cd)	DEGREE	READING (ft cd)	INTENSITY (cd)
-180.00	.00755	9.22	0.00	.01472	17.96
-179.00	.00788	9.61	1.00	.01516	18.50
-178.00	.00916	11.18	2.00	.01434	17.49
-177.00	.01013	12.36	3.00	.01350	16.47
-176.00	.01125	13.73	4.00	.01469	17.92
-175.00	.01143	13.95	5.00	.01513	18.46
-174.00	.01095	13.36	6.00	.01420	17.33
-173.00	.01032	12.60	7.00	.01340	16.35
-172.00	.00890	10.85	8.00	.01376	16.79
-171.00	.00744	9.08	9.00	.01412	17.23
-170.00	.00661	8.07	10.00	.01447	17.66
-169.00	.00575	7.02	11.00	.01564	19.09
-168.00	.00558	6.81	12.00	.01575	19.21
-167.00	.00543	6.62	13.00	.01631	19.90
-166.00	.00531	6.48	14.00	.01766	21.55
-165.00	.00538	6.57	15.00	.01655	20.19
-164.00	.00529	6.46	16.00	.01446	17.65
-163.00	.00535	6.52	17.00	.01437	17.54
-162.00	.00549	6.70	18.00	.01519	18.54
-161.00	.00566	6.91	19.00	.01586	19.35
-160.00	.00606	7.39	20.00	.01573	19.20
-159.00	.00620	7.56	21.00	.01553	18.94
-158.00	.00613	7.48	22.00	.01521	18.56
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-132.00	.01325	16.16	48.00	.01537	18.75
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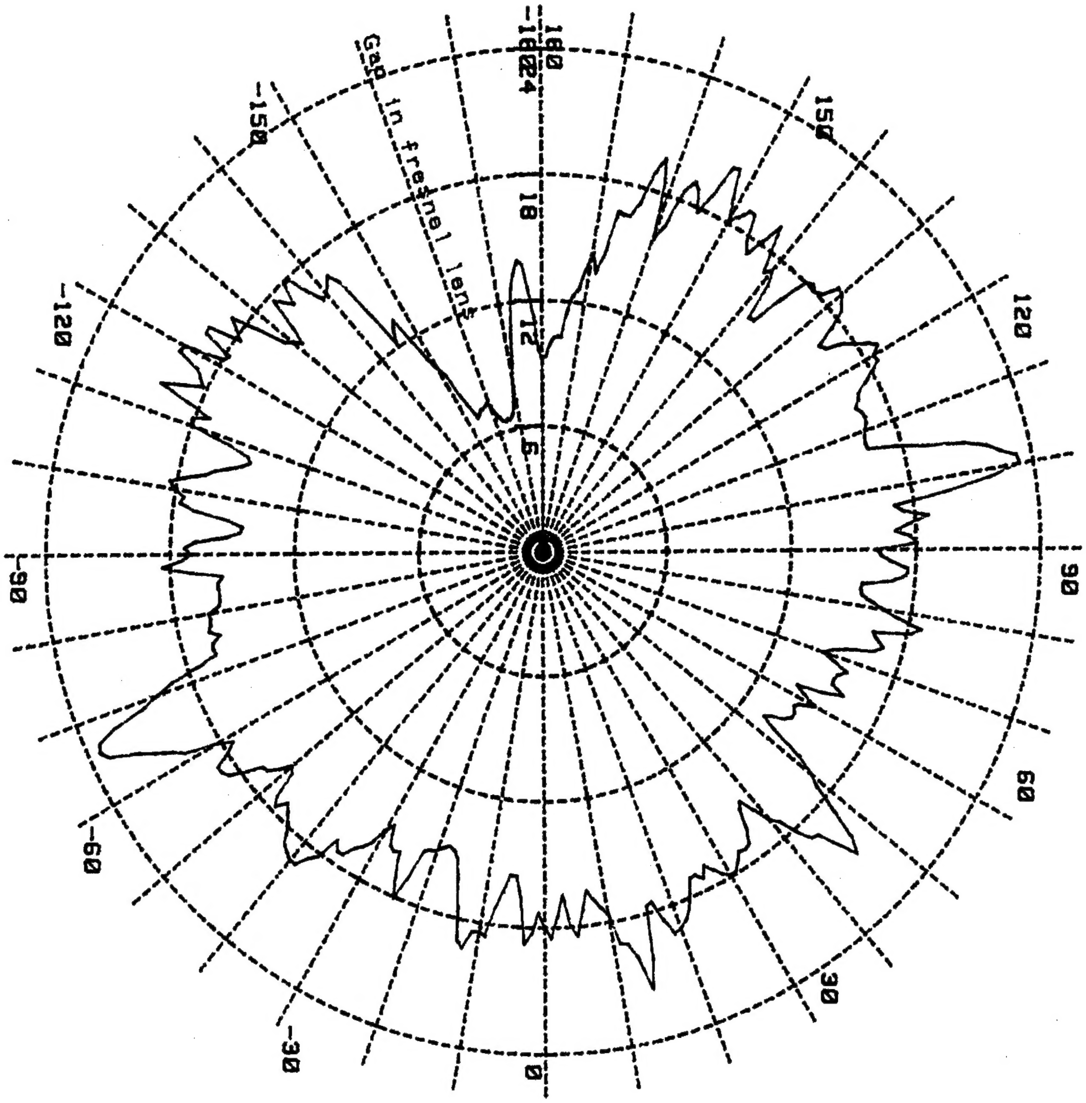

POLAR PLOT OF
HORIZONTAL INTENSITIES
Thin Film Fresnel
120 t-1 3/4 leds in circle
MAXIMUM INTENSITY: 23.42 MINIMUM INTENSITY: 6.46
MEAN HORIZONTAL INTENSITY: 16.41